Advanced Lidar Technology Project

Upendra N. Singh and Michael J. Kavaya

Systems Engineering Competency

NASA Langley Research Center

November 28, 2001

Outline

- Background
- Lidar Systems Strategy
- Code R New Initiative
- Funding and Project Plan
- Conclusions

Earth Science Independent Laser Assessment Report

Earth Science conducted an Independent Laser Assessment Review in September 2000 of its missions involving lasers and lidars.

Panel's Key Recommendations:

NASA should examine its current mechanism to bring high risk components to TRL levels necessary for a high probability of success prior to the proposal process

NASA should consider identification and intensive development of critical fundamental technology elements applicable to multiple missions

NASA needs to develop guidelines that define how basic laser technology development is carried out among the Centers and private vendors

A technology alliance should be formed among NASA, USAF, NOAA, NSF, and DOE for the development of space-based active sensors and related enabling technologies such as lasers

Integrated NASA Lidar Systems Strategy Team

GSFC/LaRC

- **Robert Afzal**, Technology Advisor, Laser Remote Sensing Branch
- **Norm Barnes**, Technology Advisor, Laser Systems Branch
- **Bruce Gentry**, Science Advisor, Mesoscale Atmospheric Branch
- **Bill Heaps,** Co-Lead, Head, Laser and Electro-optics Branch
- **Syed Ismail**, Science Advisor, Chemistry and Dynamics Branch
- **Upendra Singh,** Co-Lead, Head, Electro-Optics and Controls Branch

ESTO:

- **Frank Peri,** Instrument Program Manager

LaRC/GSFC Co-ordinators:

- **Steve Sandford**, LaRC
- **Mary Kicza**, GSFC

HQ Co-ordinator:

- **Tom Magner,** NASA, HQ

Integrated NASA Lidar Systems Strategy Team Report

Presentation to

Daniel S. Goldin, NASA Administrator

By

Ghassem R. Asrar
Associate Administrator
Earth Science Enterprise

Samuel L. Venneri
Associate Administrator
Aerospace Technology Enterprise

Jeremiah F. Creedon
Director, NASA LaRC

Alphonso V. Diaz
Director, NASA GSFC

William S. Heaps and Upendra N. Singh
Co-Leaders
Integrated NASA Lidar Systems Strategy Team (INLSST)

June 18, 2001

Draft Copy

Overview

Laser based instruments are applicable to a wide range of Earth Science, Aerospace Technology, Space Science, and Human Exploration and Development of Space Enterprise needs

Risk in lidar missions can be significantly reduced by progress in a few key technologies

Modest NASA investment towards proposed strategy will have significant impact on future space-based active remote sensing missions

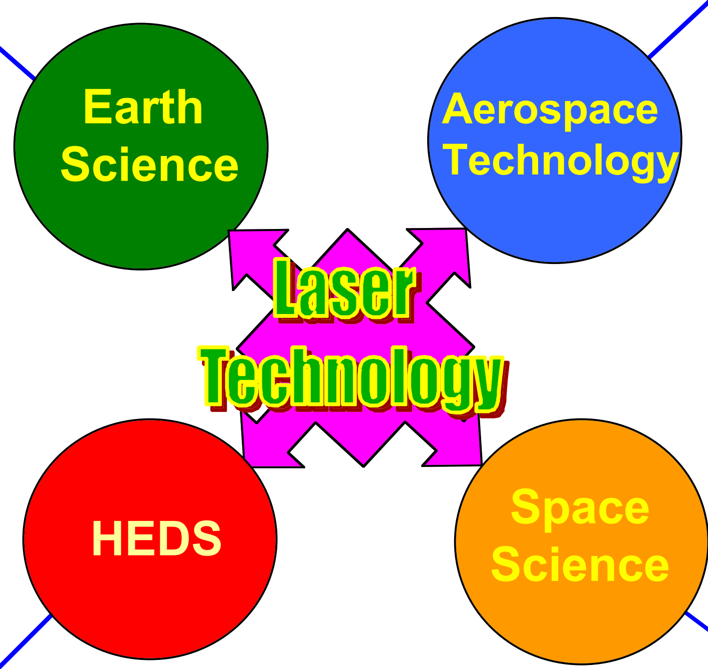
Strategic alliance with other government organizations, industry, and academia for leveraging and accelerating advancement of key technologies

Lidar is a Multi-Enterprise Need

NASA Enterprises Needs

Clouds/Aerosols
Tropospheric Winds
Ozone
Carbon Dioxide
Biomass Burning
Water Vapor
Surface Mapping
Laser Altimetry
Oceanography

Turbulence detection
Wind shear detection
Wake vortices



Automatic Rendezvous and Docking for ISS
Wind profiling for shuttle launch and landing

Mars Lander Guidance/Control
Mars Atmospheric Sensing

Earth Sciences Application Focus

2 Lasers, 4 Techniques, 6 Priority Measurements

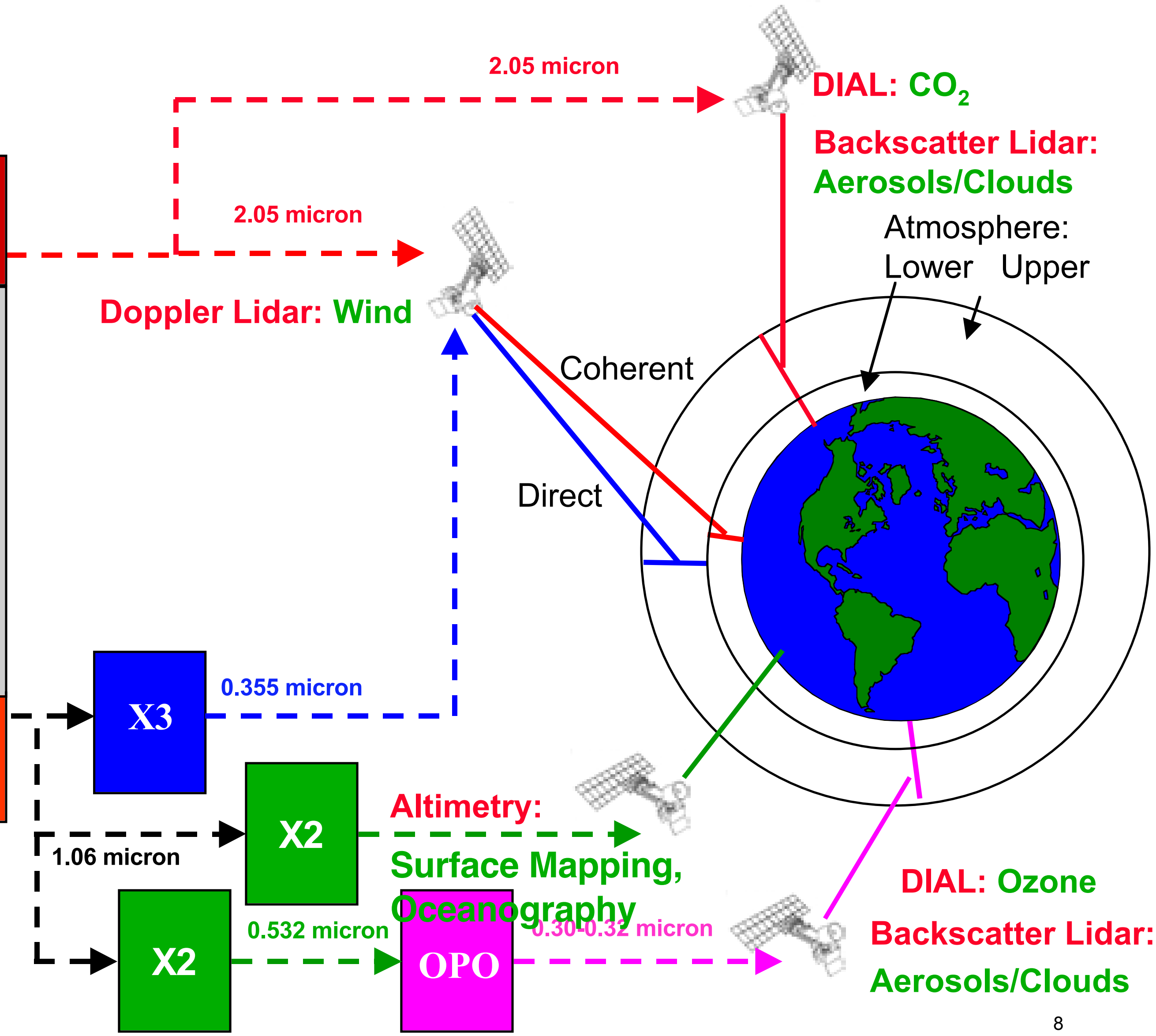
Pulsed Laser Development

2 MICRON

Key Technologies in Common

- Laser Diodes
- Laser Induced Damage
- Frequency Control
- Electrical Efficiency
- Heat Removal
- Ruggedness
- Lifetime
- Contamination Tolerance

1 MICRON



Laser Transmitter Testbeds

Contamination Tolerance
Now: 50, A/10
Goal: Better Tolerance

Laser Induced Damage
Now: 15 J/cm^2 for 5 nsec
Goal: 60 J/cm^2 for 5 nsec

Ruggedness
Now: 1 min @ 10G
Goal: 1 min @ 15 G

Lifetime
Now: 850? M shots
Goal: 2 G shots

Heat Removal
Now: 110 Watts
Goal: 300 Watts

Frequency Control
Now: < .25 pm
Goal: < .005 pm

Electrical Efficiency
Now: 3-4%
Goal: 6%

2 μ Test Bed
1 μ Test Bed

Knowledge

Recommendations

- Establishing Space-hardened Laser Transmitter Test Beds (1μm laser at GSFC & 2μm at LaRC)

- Development and Qualifications of Space-based Laser Diode Arrays

- Advancing Wavelength Conversion Technology for Space-based Lidars

Advanced Active Instrument Technology

Proposed Initiative for FY03

Code R

Advanced Active Instrument Technology

- **Major Program Elements**
  - Space-hardened Advanced Laser Transmitter Technologies Test Beds
  - Efficient, High-power, Conductive-cooled Space-hardened Laser Diode Arrays Technologies
  - Non-linear Optical Parametric and Harmonic Generation Technologies
  - **“Intelligent” Receivers, Tunable, Processing at the Focal Plane**
  - **Life Prediction Methods**

- **Budgetary Resources ($M)**

FY 03	FY 04	FY 05	FY 06	FY 07
12.0	**16.0**	**16.0**	**16.0**	**10.0**

Advanced Lidar Receiver Technologies

Advanced Lidar Receiver Technology with active/intelligent devices is critical to successful development of relatively large aperture space-based Lidars.

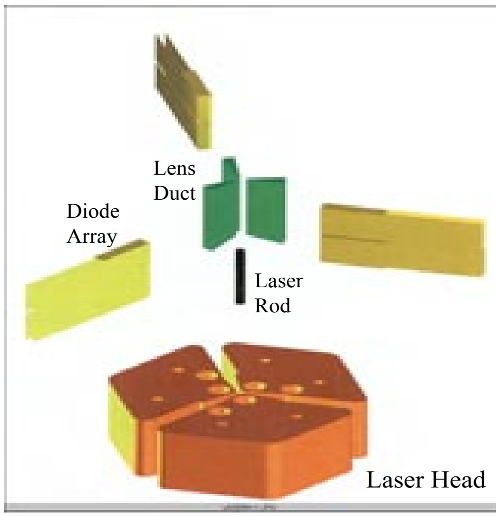
Advanced Lidar Receiver Technology **can be classified under four major elements:**

- **Automatic Optical Alignment**
  Active pixel array technologies combined with **intelligent autonomous controller** to maintain instrument optical alignment and correct for distortions
- **Integrated Photoreceiver**
  Integrating **detectors**, **processing electronics**, and **Tunable Semiconductor Local Oscillator Laser**, on a single chip for improved lidar sensitivity and robustness.
- **Scanner**
  Non-mechanical electro-optical devices to mitigate many technical issues associated with the scanning lidar instruments.
- **Lightweight Lidar Telescope**
  Advanced telescope technologies leading to **Meter-class** lightweight telescope are needed for Coherent Doppler and Backscatter Lidars. **Multi-meter Deployable** Telescopes are critical to DIAL applications.

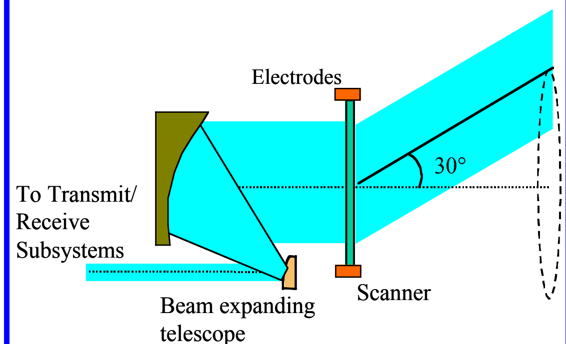
Deliverables - Proof of concept test bed for advanced lidar receivers applicable to direct and coherent lidar systems

Major Lidar Technology Elements

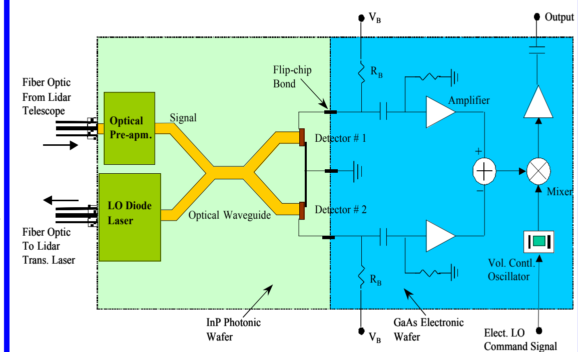
Lidar Transmitter



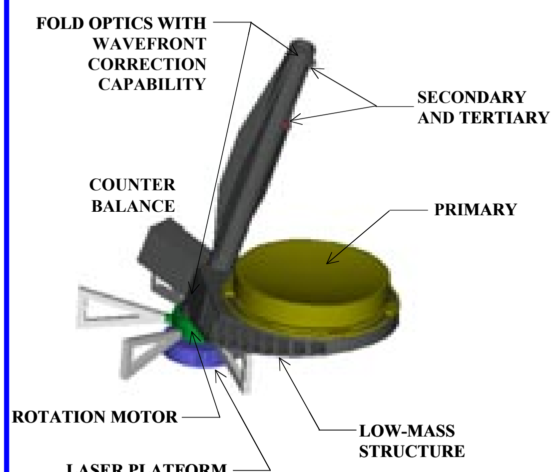
Electro-Optic Scanner



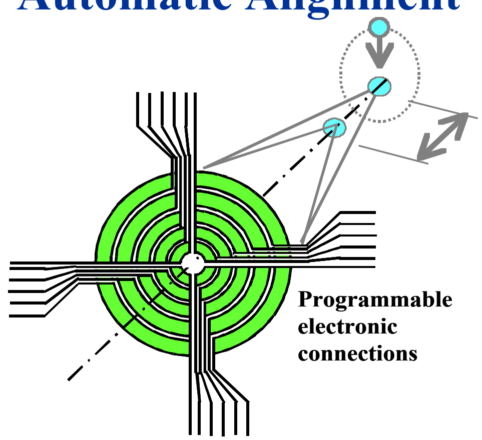
Integrated Photoreceiver



Lightweight Telescope

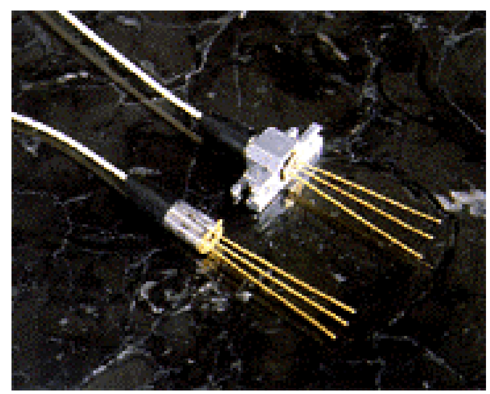


Automatic Alignment



Schematic of PLZT-based Adjustable Focus and tip/tilt, and Aberration Correction

Low-Noise Detector



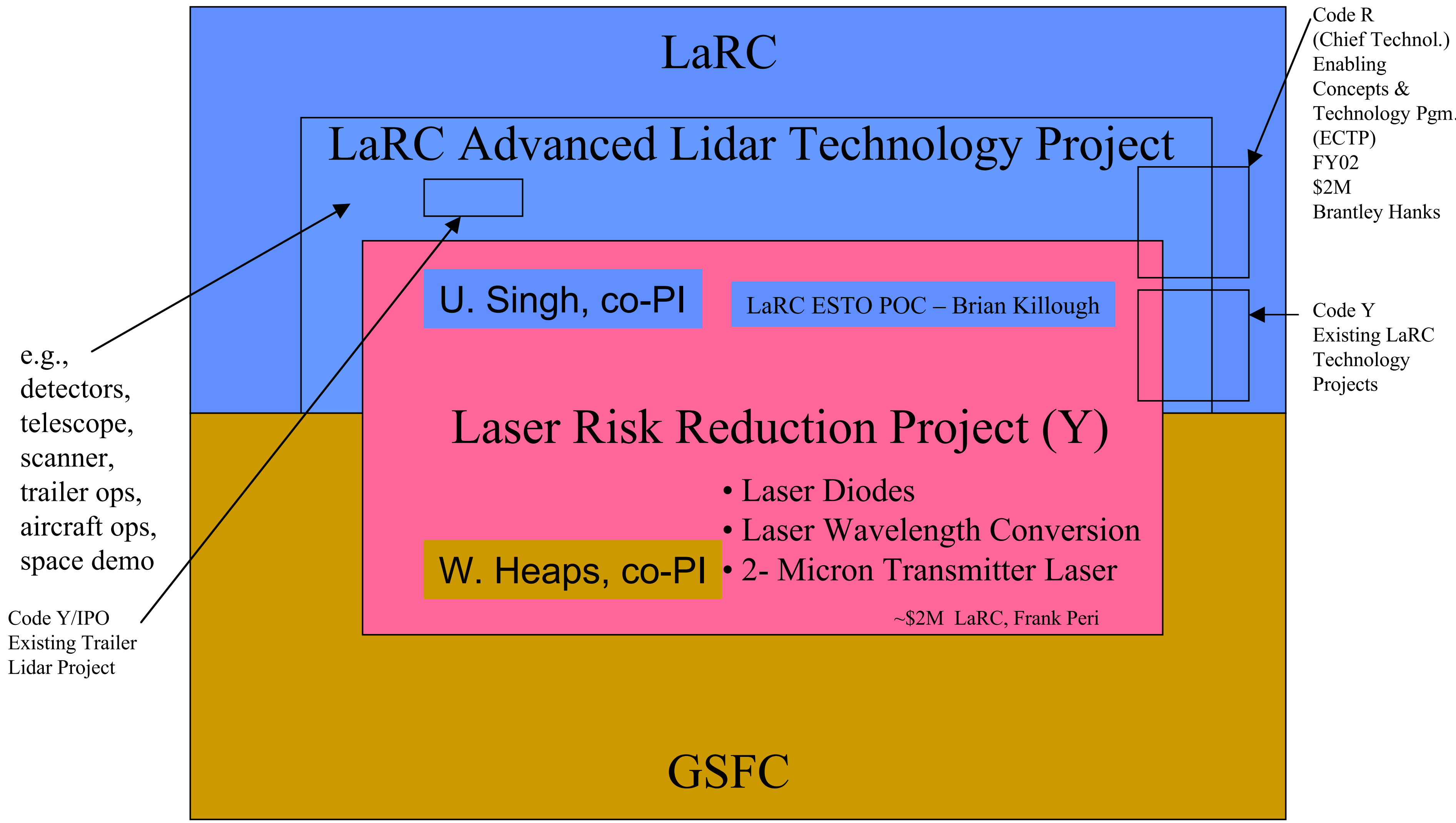
Status Of Proposal

- FY02 Code Y Start Money Approved ($4M, ~ LaRC PI- U. Singh, GSFC PI- W. Heaps)

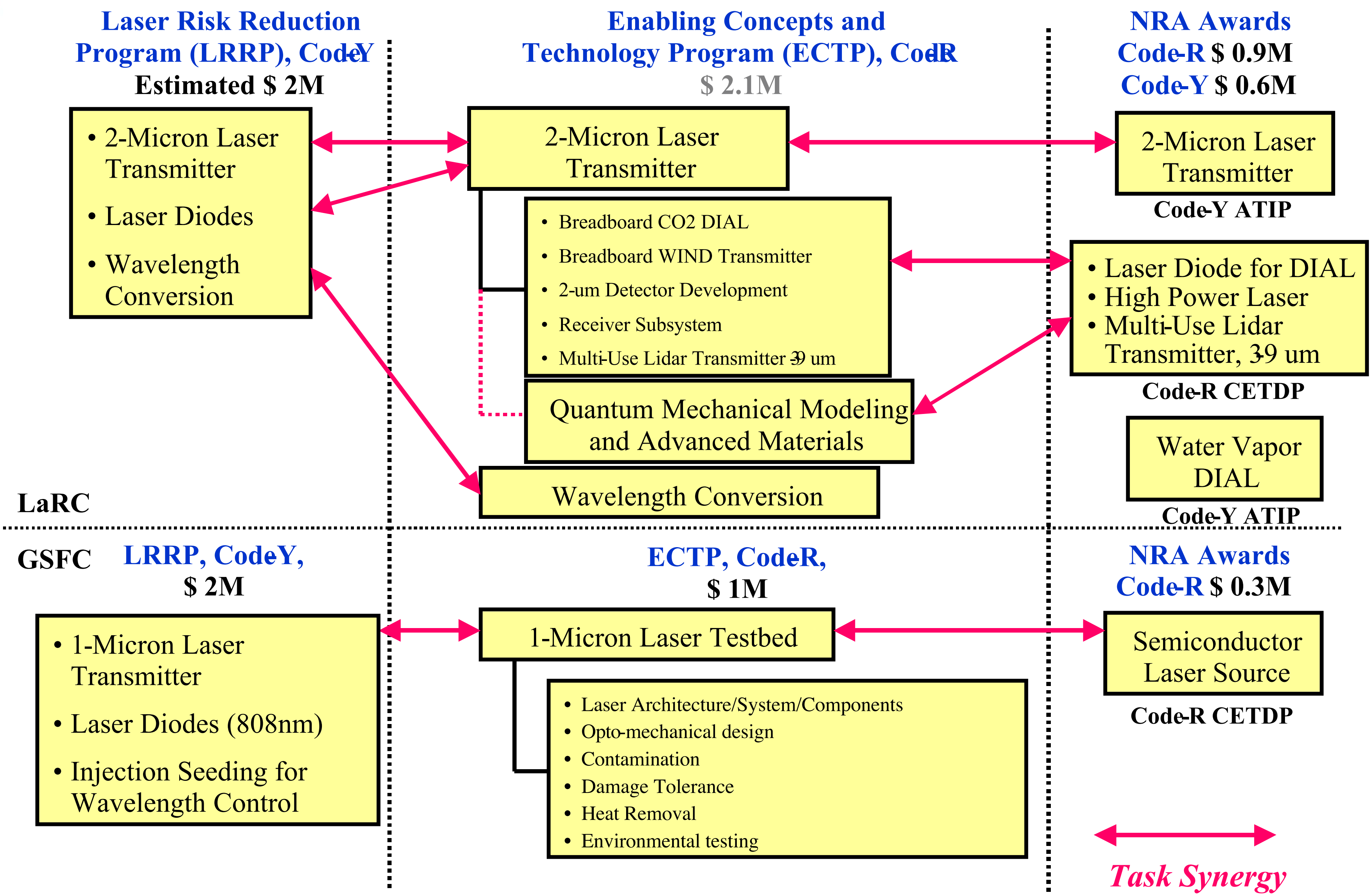
- FY02 Code R Start Money Approved ($2M to LaRC, $1M to GSFC)

- Code R New Initiative Request was presented to OMB for New Line Approval for FY03 ($ 70M for FY 03-07)

Advanced Lidar Technology Project



FY02 Joint Laser Technology Program



Advanced Lidar Technology Project

Project Manager
Michael J. Kavaya

Lidar Systems Engineer – Farzin Amzajerdian
Business Manager – Jennifer McCardell
Resource Analyst – TBD
ESTO/Code R Tech. Mgr. – Brian Killough

Laser Risk Reduction PI
Upendra N. Singh

Science/Technology Advisory Committee
James Barnes, Norman Barnes, Syed Ismail, Steve Sandford

Transmitter Laser
Jirong Yu
- Pump Diodes (Byron Meadows)
- Design/Analysis
- Lifetime
- Contam.
- (M. Petros)
- Crystal Research (V. Sudesh)
- Breadboard Lasers
- Freq. Control Syst. (M. Petros) (Keith Murray)
- QM Modeling & Advanced Laser Materials (N. Barnes)

Wavelength Conversion
TBD
- Crystal Res.
- Nonlinear Conv.
- OPO Cavities
- Spectroscopy (C. Edwards) (L. Petway)

Opt./Rec. Sys.
Farzin Amzajerdian
- Telescope
- Scanner
- Autoalignment
- Integrated Rec.

Detectors
Nurul Abedin
- Detectors
- Charact. Facilities (T. Refaat)

Electronics
TBD
- Signal Proc. SW
- Display
- Control Electronics
- Data Acq./Processor (C. Mills)
- Electronic Receiver
- Aircraft Interfaces

Lidar Int./Ops
Grady Koch
- Breadboard Syst.'s (M. Petros)
- Trailer Lidar (B. Barnes)
- Field Meas.'s (M. Petros)
- A/C Syst. Int./Ops
- Calibration Facility (V. Sudesh)

Systems Analyses/Sim
M. Kavaya
- Modeling
- Syst. Req'ments
- Cal/Val
- Data Analyses (P. Brockman)

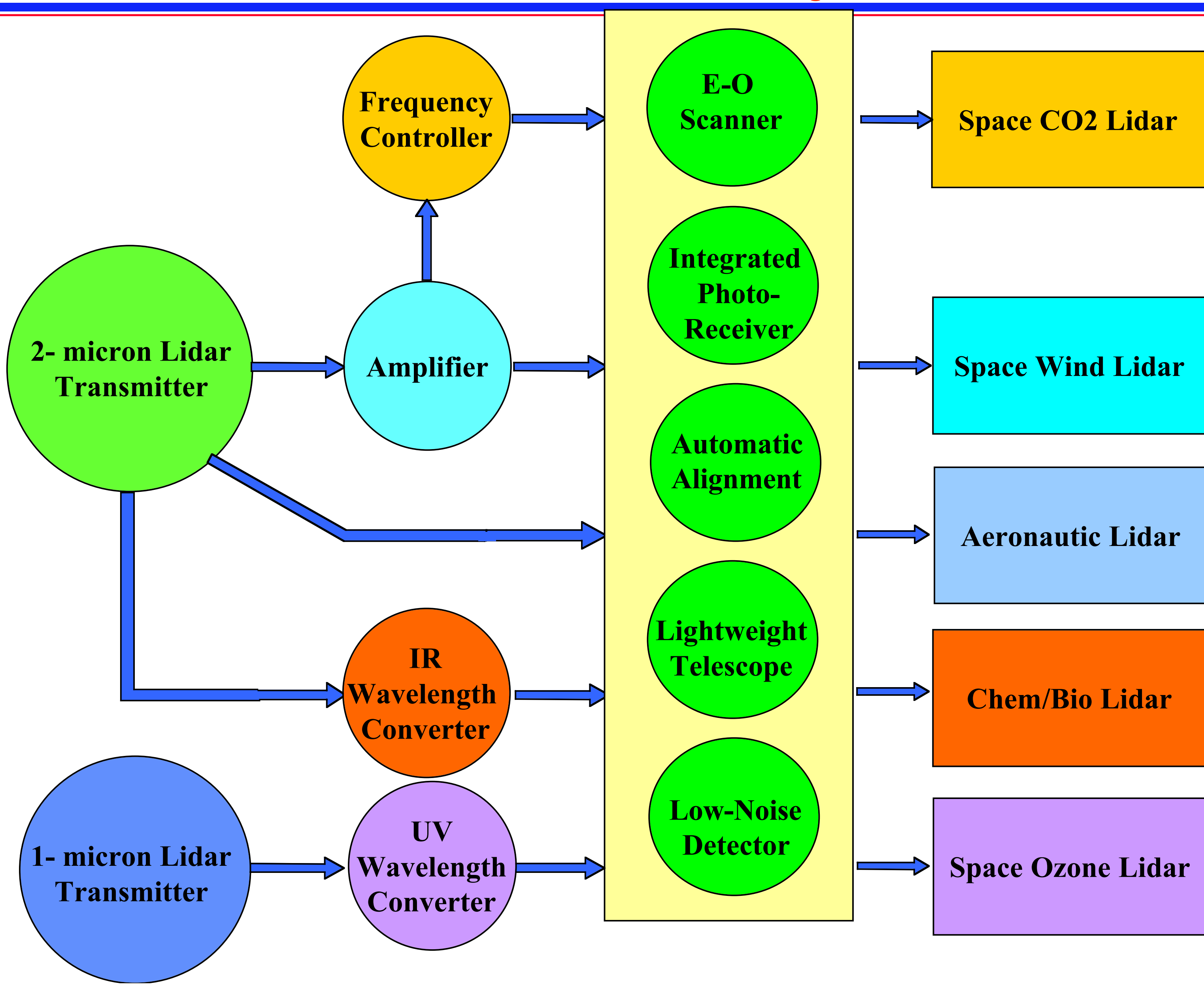
Thermal, Mech. Eng., Fabrication
- Thermal
- Mechanical
- Fabrication

ALTP Charter

- Develop lidar technology for NASA's future measurements
- Assemble in-house NASA team with <u>end-to-end</u> lidar capability (theory to hardware to validation)
- Collaborate with industry, academia, and government
- Validate technology to reduce risk of space-based lidar missions <u>before</u> the proposal process
- Transfer technology to industry

End-to-End Lidar Capabilities

Lidar Technologies



Conclusions

- INLSST formulated a multi-enterprise Integrated NASA lidar system strategy for addressing critical technological deficiencies cited by External Peer Review Committee
- Team presented the program (technical, schedule, cost) to Center Directors, Associate Administrators and secured their advocacy
- Team presented the Lidar System Strategy to NASA Administrator and received his approval for funding in FY 02 and a go-ahead for a new Code R initiative in FY 03
- Team developed a $70M Code-R New Initiative Proposal. Capital Investment Council has approved it. Awaiting OMB approval
- Team expects to receive $7M in FY 02 fund from Code Y and R to implement the strategy

Backup Slides

Advanced Active Instrument Technology Deliverables

Near Term

- 1 and 2-micron Laser Transmitter Test Bed
  - Trade off studies for oscillators and amplifiers designs
  - Trial designs for conductive cooling
  - Prototype laser package designs
- Laser Diode Qualification
  - Identification of potential sources
  - Diode testing protocols and testing facilities
- Related Tunable Technologies - Non-linear optics test facilities
- Advanced Lidar Receiver Technologies -Active pixel array technologies, deployable and lightweight telescope

Program End

- Space-hardened 1- and 2-micron Laser Transmitters (Efficient, conductively-cooled)
- Space-hardened Conductively Cooled Laser Diode Arrays
- Non-linear Optical Parametric and Harmonic Generation for Ozone, Chemical and Biological Species, and Carbon Dioxide Detection
- Advanced Lidar Receivers for Direct and Coherent lidars
- Life Prediction Methods for Active Instrument Components

Advanced Active Instrument Technology

Lead and Performing Center Roles

Overall lead for Code R Advanced Active Instrument Technology Program element - LaRC

- **Advanced Active Instrument Technology (LaRC)**
  - 2-micron Laser Transmitter Test Bed Implementation – LaRC
  - 1-micron Laser Transmitter Test Bed Implementation– GSFC
  - Non-Linear Optical Parametric Technologies Developments– LaRC
  - Harmonic Generation Technology Development – GSFC
  - Laser Diode Arrays Development – LaRC and GSFC Collaboration
  - Participation in Space Technology Alliance - LaRC and GSFC Collaboration
  - "Intelligent" Receivers, Tunable, Processing at the Focal Plane – LaRC, JPL and ARC
  - Life Prediction Methods - LaRC and ARC

Funded FY02 Activities

Code Y/ESTO (New)

- Laser Diode Test Facility & Improvement
- Laser Wavelength Conversion Technology
- 2-Micron Laser Transmitter Technology

Code R (New)

- 2-Micron Laser Transmitter Technology
- Quantum Mechanical Modeling; New Materials
- Laser Wavelength Conversion Technology
- Detector Technology
- Integrated Lidar Receiver Technology

Code Y (Existing)

- 2-micron Lidar Transmitter
- Water Vapor Lidar

Code R (Existing)

- Multiple Lidar Transmitter

Code Y and IPO (Existing)

- Lidar Trailer Activities
- Lidar Wind Data Buy Support

Acknowledgements

INLSST Team

- –Robert Afzal
- –Norm Barnes
- –Bruce Gentry
- –Bill Heaps
- –Syed Ismail

LaRC Support Team

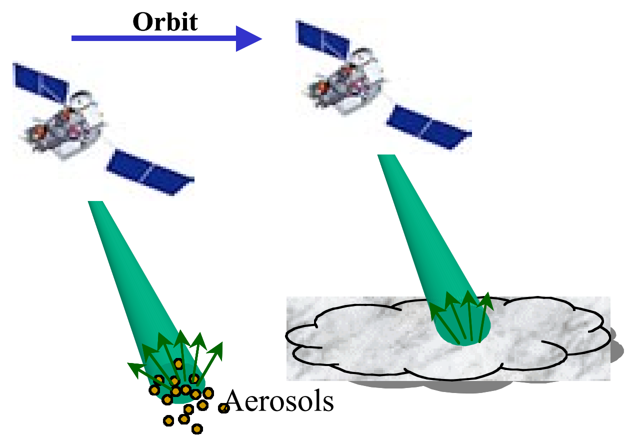
- –Jerry Creedon
- –Ruth Martin
- –Steve Sandford
- –Glenn Taylor
- –Carl Gray
- –Lenny McMaster
- –Michael Kavaya
- –Farzin Amzajerdian
- –Edward V. Browell
- –James Barnes
- –Barry Meredith
- –Brian Killough

HQ/GSFC Team

- –Sam Venneri
- –Ghassem Asrar
- –Tom Magner
- –Brantley Hanks
- –Al Diaz
- –George Komar
- –Mary Kicza
- –Frank Peri

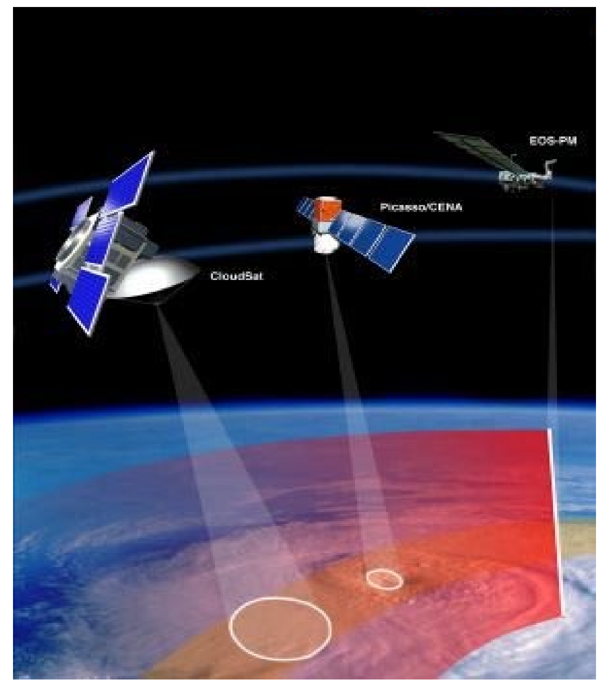
Advanced Active Instrument Technology

Backscatter Lidar



Measurements:
- Cloud Base and Top Heights
- Cloud Density
- Aerosol Concentration
- Provide Transport Data and Seasonal Changes

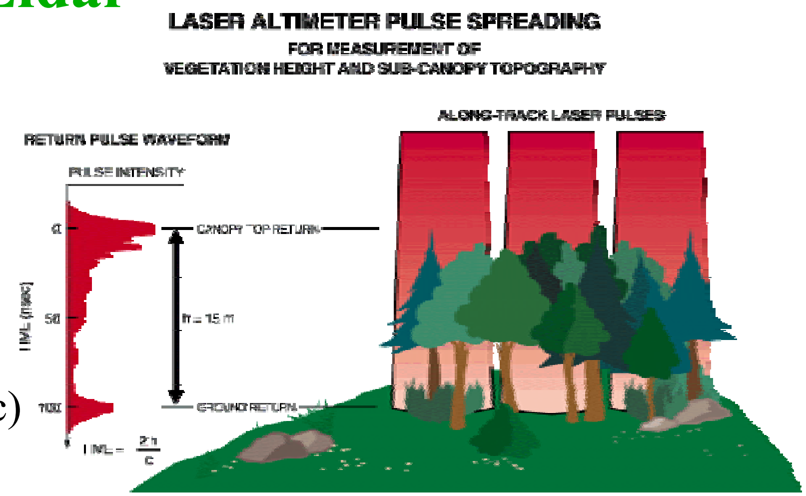
Instrument Description:
- Transmit short/medium duration laser pulses (10 nsec < τ_p < 100 nsec)
- Reflected photons are collected by a telescope
- Intensity and polarization of reflected light provide Aerosol and Cloud density and effective particle size
- Pulses round-trip time provide accurate Aerosol and Cloud vertical distributions



Instrument Attributes:
- Non-scanning
- Meter class Telescope
- 20 W class Laser
- Level of Complexity: Moderate-to-High

Advanced Active Instrument Technology

Altimeter Lidar



Measurements:

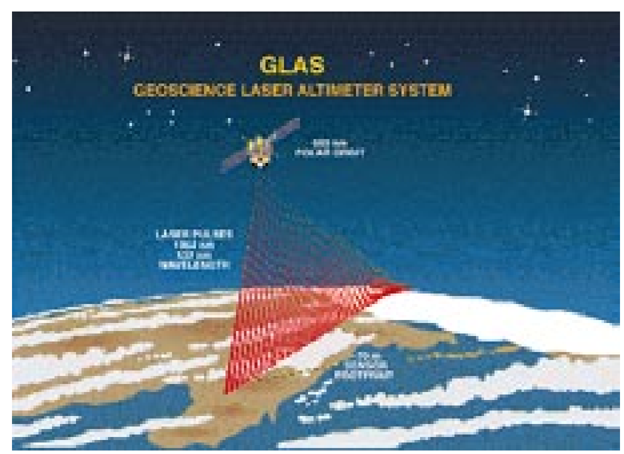
- Vegetation and Land Topography
- Ice Sheet Mass Balance
- Ocean Surface and Current Flow
- Provide Associated Temporal Changes

Instrument Description:

- Transmit short duration laser pulses (τ_p < 5 nsec)
- Reflected photons are collected by a telescope
- Pulses round-trip time provide accurate distances to targets of interest
- More sophisticated signal processing allows for measurements of extended targets such as vegetation height

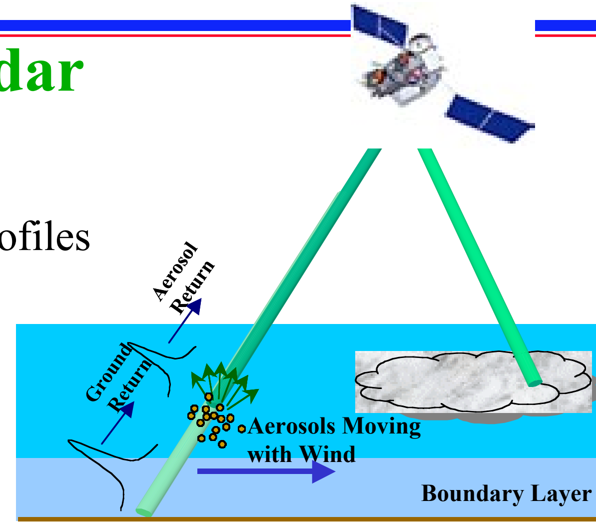
Instrument Attributes:

- Non-scanning
- Sub-meter class Telescope
- Sub 10 W class Laser
- Level of Complexity: Moderate



Advanced Active Instrument Technology

Coherent Doppler Lidar

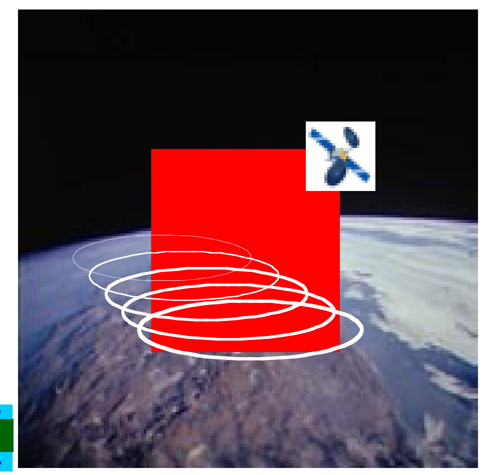


Measurements:

- Boundary Layer and Lower Troposphere Wind Velocity Profiles
- Cloud Height and Velocity
- Aerosol Concentration
- River Flow

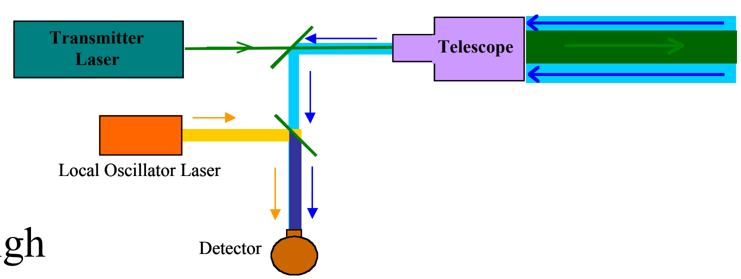
Instrument Description:

- Transmit medium duration laser pulses (τ_p > 200 nsec)
- Reflected photons from atmospheric aerosols are collected by a telescope
- Wavelength of the backscattered light is Doppler shifted by aerosols moving with wind
- Doppler shift is measured using heterodyne detection similar to FM radio

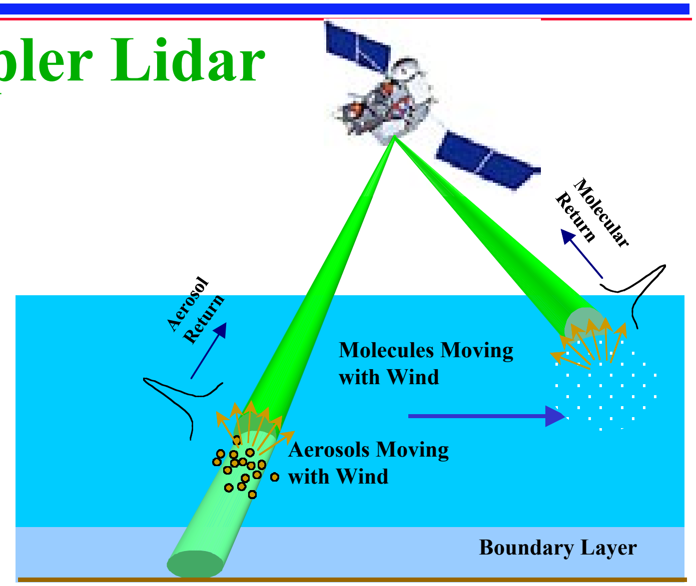


Instrument Attributes:

- Scanning
- Meter class Telescope
- 10 W class Laser
- Level of Complexity: High



Direct Detection Doppler Lidar



Measurements:

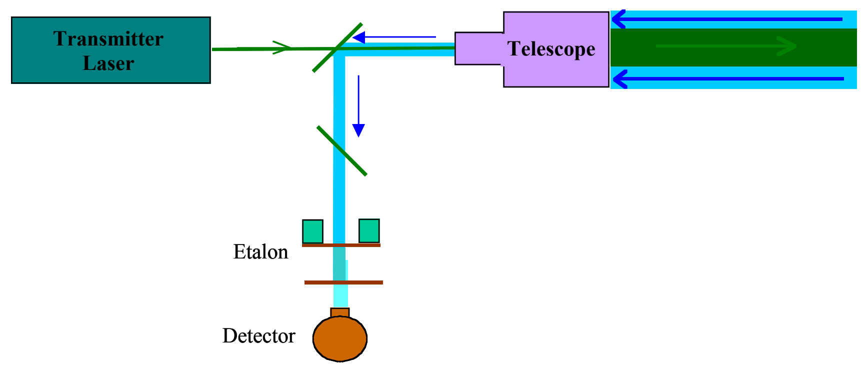
- Troposphere Wind Velocity Profiles
- Cloud Height

Instrument Description:

- Transmit short duration laser pulses (τ_p < 20 nsec)
- Reflected photons from atmospheric molecules and aerosols are collected by a telescope
- Wavelength of the backscattered light is Doppler shifted by molecules and aerosols moving with wind
- Doppler shift is measured using Fabry Perot Etalons

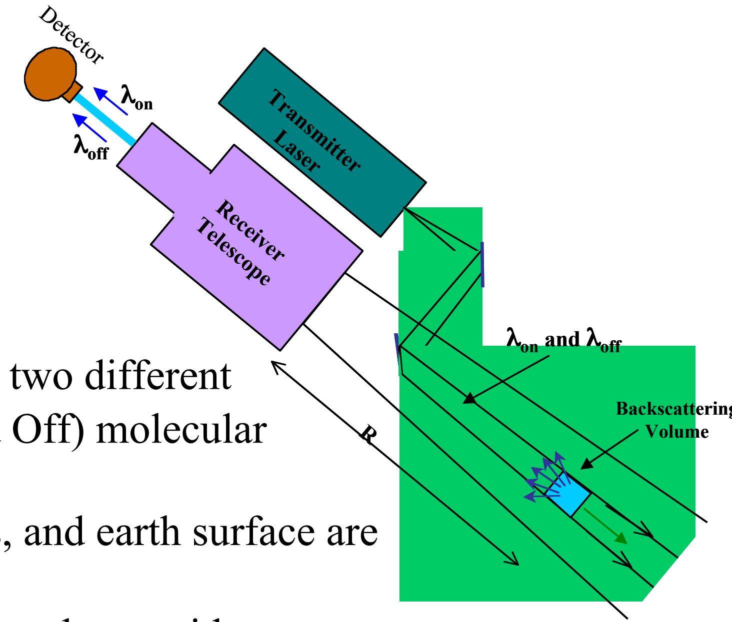
Instrument Attributes:

- Scanning
- 2-Meter class Telescope
- 30 W class Laser
- Level of Complexity: High



Advanced Active Instrument Technology

Differential Absorption Lidar (DIAL)



Measurements:

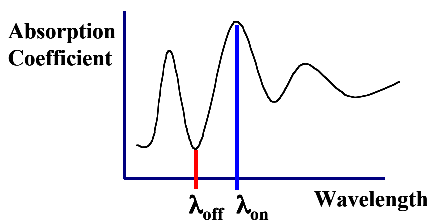
- Carbon Dioxide (CO_2) Concentration Profiles
- Ozone (O_3) Concentration Profiles
- Cloud Base and Top Heights, and Density
- Aerosol Concentration

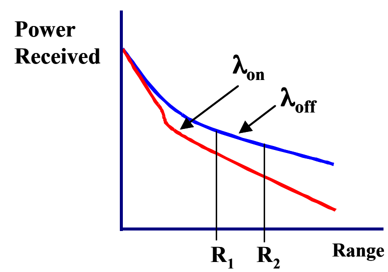
Instrument Description:

- Transmit short duration laser pulses ($\boldsymbol{\tau_p}$ < 20 nsec) at two different wavelengths, corresponding to high and low (On and Off) molecular absorption lines
- Reflected photons from atmospheric aerosols, clouds, and earth surface are collected by a telescope
- Ratio of the backscattered light at On and Off wavelengths provides molecular concentration
- CO_2 is measured by a 2-micron lidar and O_3 by a 0.3-micron lidar

Instrument Attributes:

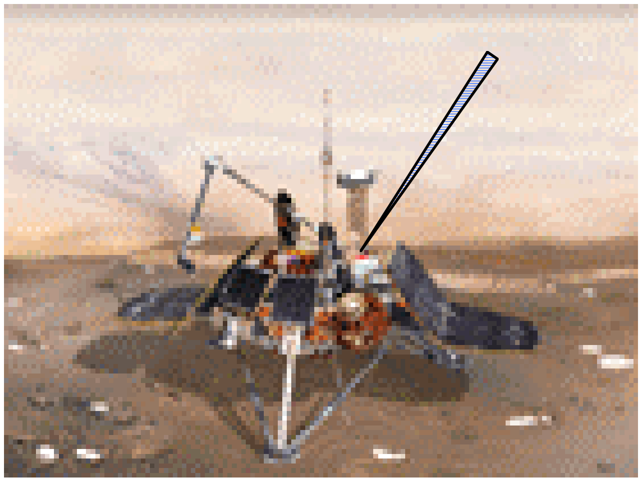
- Non-scanning
- 2-Meter class Telescope
- 10 W class Laser
- Level of Complexity: High





Advanced Active Instrument Technology

SPACE SCIENCE MISSIONS

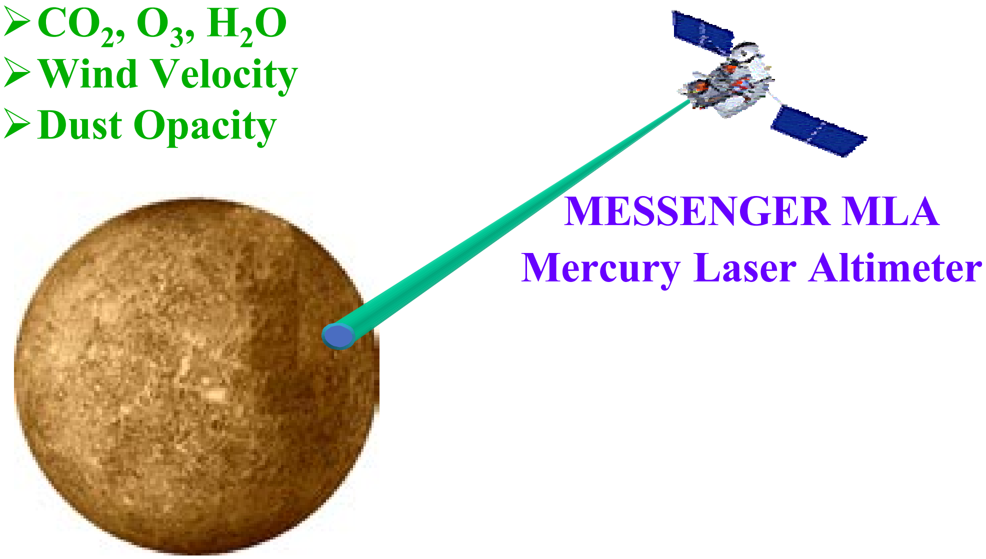


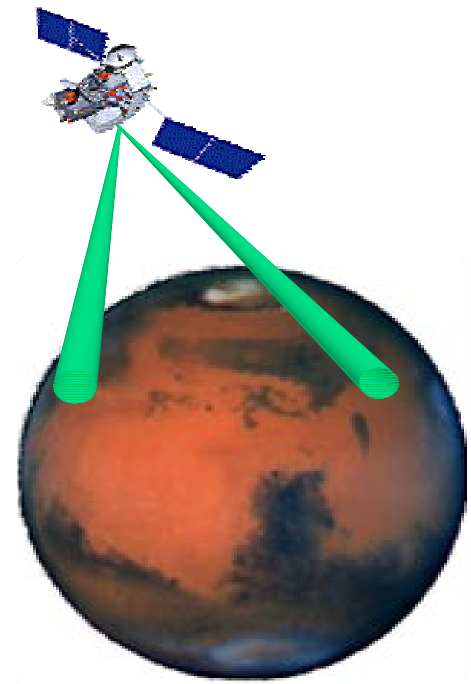
Planetary Lower Atmosphere Sensing

- CO_2, O_3, H_2O
- Wind Velocity
- Dust Opacity

Planetary Orbiting Lidars

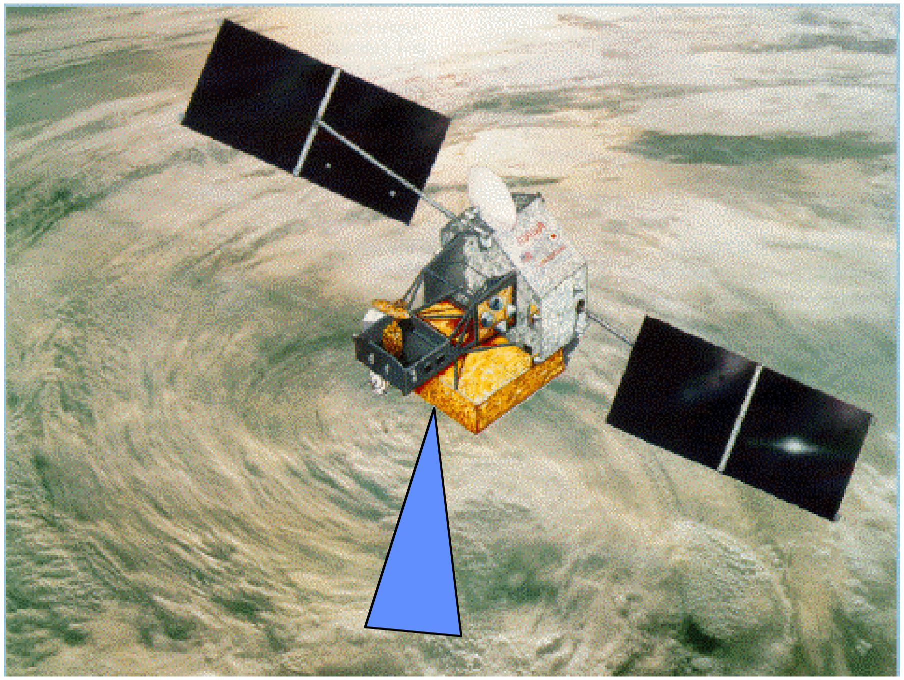
- Concentration, distributions, and variations of CO_2, O_3, H_2O
- Wind fields and seasonal variability
- Altimetry and Surface Topography





Lidar for Earth Sciences Enterprise

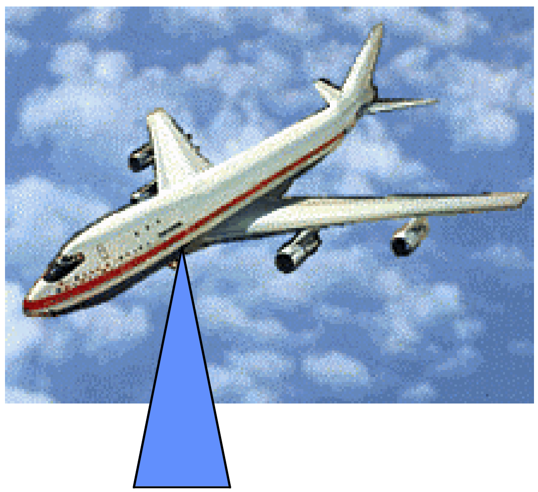
Lidar Instruments are capable of providing high vertical resolution global measurements of Ozone, Carbon dioxide (CO_2), water vapor, and aerosol concentration from space. Laser altimeters can provide surface mapping, ice topography, and ocean stream/current measurements from space



ESE recognizes the merits of Lidar technology for achieving these measurements.

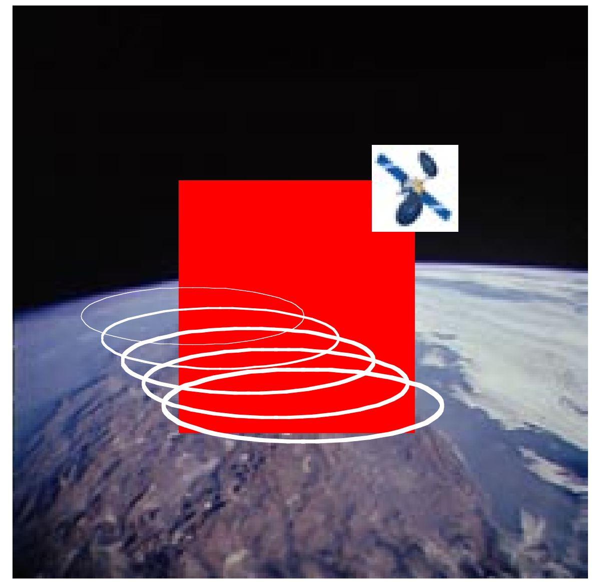
Lidar for Earth Sciences Enterprise

Lack of accurate global wind data has been cited by the ESE as a major missing component in the presently planned set of measurements



Lidar wind measurements from an aircraft provide valuable data for:

- **Scientific investigation of sub-grid processes and features in climate and global change models**
- **Assessment of the performance of proposed space-based Doppler lidars**
- **Provide calibration and validation data for space-based Doppler lidars**



"Direct tropospheric wind measurements would provide a greater impact on numerical weather prediction models than any other new space-based observation." **- NPOESS IPO, 1996.**